Lithofacies and Depositional Environmental Interpretation of Well Logs Within Akos Field, Coastal Swamp Depobelt of The Niger Delta

By

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Abstract

Ten hydrocarbon-bearing sands (A-J) penetrated by eight (8) wells drilled within the Akos Field in the Coastal Swamp Depobelt of the Niger Delta were investigated for their lithofacies and depositional environment. The assessment of the lithofacies and the environment of deposition was based on the analysis of the gamma-ray log. Four lithofacies were recognized in the study area based on the energy trend of log signatures and they include: coarse-grained sandstones facies with blocky log pattern, sand-rich heteroliths, and mud-rich heteroliths composed of shales intercalated with thin siltstone as well as mudstones. The environments of deposition delineated in the Akos field include upper shoreface, lower shoreface, fluvial channel, shelf, and tidal. Interpretation of biofacies data indicates that the sediments were deposited within the shallow Inner-Neritic to the Middle-Neritic environments at various times consistent with the progradational mode of deposition in the Niger Delta.

Keywords: Niger Delta; Lithofacies; Depositional environment; Gamma-ray log; Log signature; Coastal Swamp Depobelt.

Introduction

The Niger Delta Basin is composed of sedimentary successions with heterogeneity that give rise to complex sedimentary facies that often appear as chaotic and unpredictable. To optimize oil production from the reservoirs requires sand-sand correlation that would allow for the determination of their interconnectivity based on the character of gamma-ray logs and the biostratigraphy data. The task in this study is to interpret reservoir facies from log signatures and changes in sediment accumulation in order to determine the distribution of the depositional environments in the Akos field. It is located around latitude 4° 19′ north and longitude 6° 02′ east in the Coastal Swamp Depobelt of the Niger Delta Basin (Fig.1). Figure 2 shows the locations of wells on the field.

Evolution and Stratigraphy of the Niger Delta Basin

The Niger Delta Basin is located at the convergence of the Benue Trough and the South Atlantic Ocean where a triple junction developed during the separation of South America and Africa continent in the Late Jurassic [1]. This was followed in Early Cretaceous times by subsidence of the African continental margin due to the cooling of the newly created oceanic lithosphere. The evolution of the Niger Delta started in the Early Tertiary times when clastic river input increased.[2] The stratigraphic sequence of the Niger Delta is comprised of an upward-coarsening regressive association of Tertiary clastics up to 12 km thick (Fig. 3). Informally, it is divided into three major

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[1] Whiteman, A., 1982. Nigeria—its petroleum geology, resources, and potential: London, Graham and Trotman, p. 394

[2] Doust, H. and Omatsola, E., 1990. Niger Delta: in Edwards, J. D., and Santogrossi, P.A., (Eds.), Divergent/passive margin basins: American Association of Petroleum Geologists Bulletin Memoir 48, p. 239-248.

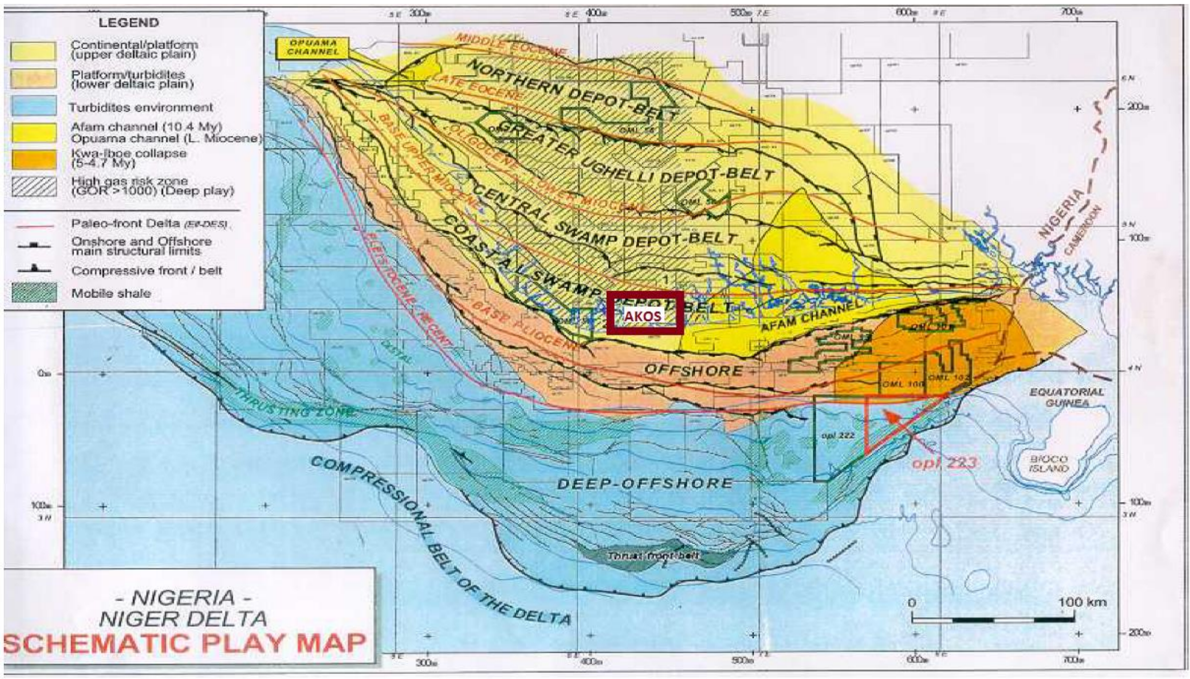

Fig. 1: Map of Niger Delta Basin showing the study location marked as Akos Field (SPDC)

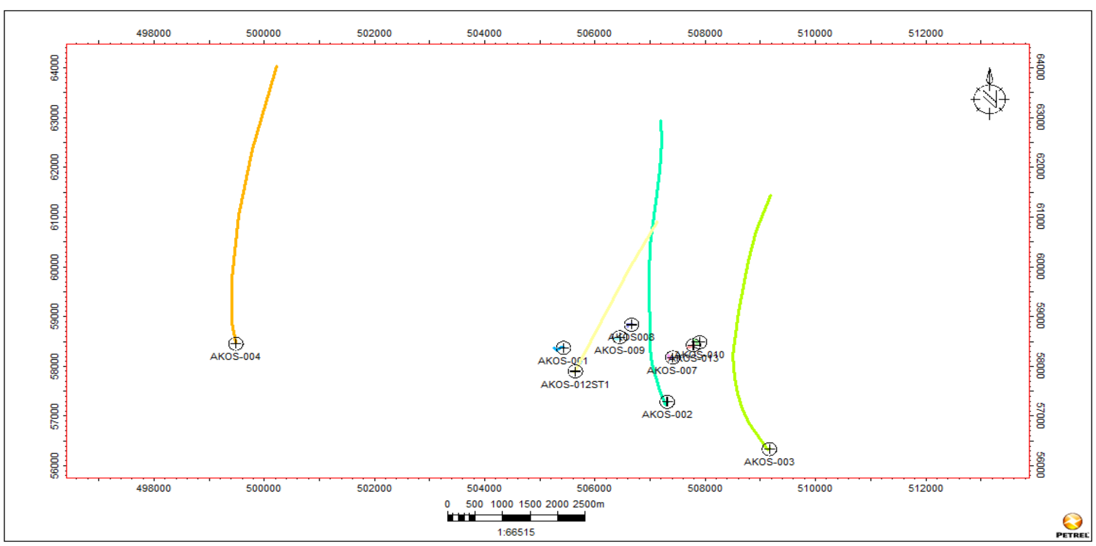

Fig. 2: A base map showing the location of eight wells in the AKOS Field.

lithofacies namely the marine claystones and shales of unidentified thickness at the base, with an alternation of claystones, sandstones, and siltstones with an upward increasing sand percentage. Three lithostratigraphic units have been recognized in the subsurface of the Niger Delta). These range from the oldest to the youngest – the Akata, Agbada, and Benin Formations all of which are strongly diachronous [3].

The oldest lithostratigraphic unit of the Niger Delta is the Akata Formation of marine origin located at the base of the delta, with a thickness range of 2000 m to 7000 m [4]**.**
Agbada Formation overlies the Akata Formation and exists throughout the Niger Delta. It represents the main hydrocarbon-bearing formation whose deposition began in the Eocene and continued into the present[5]. The lithologies are characterized by paralic interbedded sandstone and shale thickness of over 3,000 m [6] with alternation of sands, silts, and shales arranged within ten to hundred feet successions and well-defined by progressive upward changes in grain size and bed thickness. These paralic clastics are the true deltaic portion of the sequence and were deposited as of delta-front, delta-topset, and fluviodeltaic environments.

The Benin Formation is the youngest lithostratigraphic unit in the Niger. It is Miocene –Recent in age with a minimum thickness of more than 1800m and made up of continental sandstones (>90%) with minute shale intercalations.

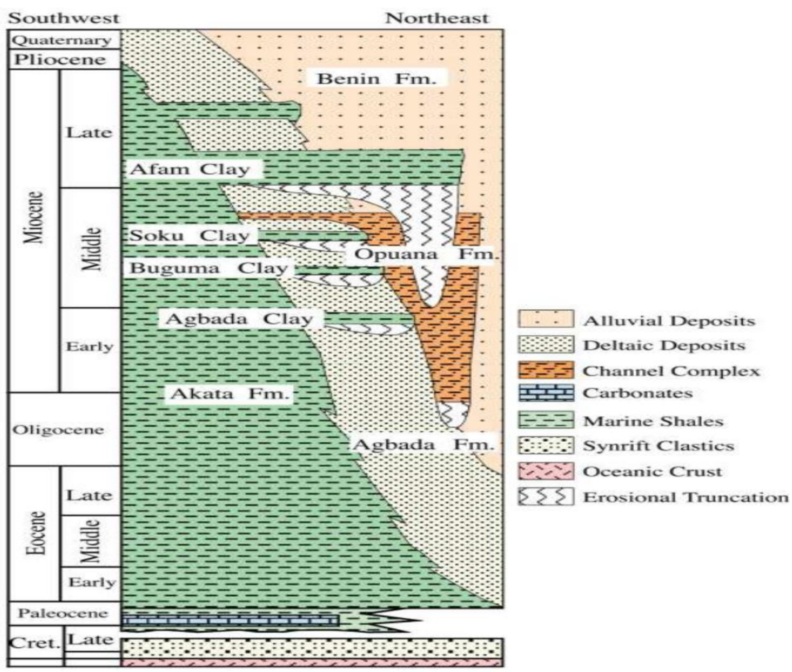

Fig. 3: **Stratigraphic column showing the three formations of the Niger Delta [7]**

Materials and Method

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[3]Short, K. C., and Stauble, A. J., 1967. Outline of the geology of Niger Delta. American Association of Petroleum Geologists Bulletin, Vol. 51, p. 761-779.
[4] Avbovbo, A. A., 1978. Tertiary lithostratigraphy of Niger Delta. American Association of Petroleum Geologists Bulletin, Tulsa, Oklahoma, p. 96- 200
[5] Corredor, F., Shaw, J. H. and of Petroleum Geologists Bulletin, Billoti, F., 2005.Structural styles in the deep-water fold and thrust belts of the Niger Delta: American Association Vol. 89, p. 753–780
[6] Reijers, T.J.A. 1996. Selected Chapters on Geology: with notes on Sedimentary Geology, Sequence Stratigraphy and three case studies and a field guide. S.P.D.C. Corporate Reprographic Services, Warri, Nigeria. 197p.
[7] Lawrence, S.R., Munday S., and Bray, R., 2002. Regional geology and geophysics of the eastern Gulf of Guinea (Niger Delta to Rio Muni): The Leading Edge, Vol. 21, pp. 1112– 1117

The Shell Petroleum Development Company of Nigeria provided the data set used for this study:

a) Suites of well logs from eight (8) wells including gamma ray (GR) and resistivity (laterologs) logs.
b) Biostratigraphic data comprising the biofacies data, palynological zone (P-Zone) and Foraminifera zone (F-Zone).

Well Log Analysis

Eight (8) well logs were imported to the Petrel software and used for lithologic identification. The method involved delineation of lithologies with the aid of gamma-ray log signatures (Fig. 4). A shale reference line of 75 American Petroleum Institute (API), selected from a range of 0–150 API was used in distinguishing between the shale and sand lithologies on the gamma-ray log. This is in response to the natural radioactivity of the formation. The gamma-ray log was also employed for the lithologic identification of the reservoir (sand-sand correlation). The hydrocarbon bearing sands were identified and their correlation allowed for the establishment of the lateral continuity of the subsurface hydrocarbon reservoir facies penetrated by the wells. The log trends were used in the delineation of the lithofacies and depositional environments (Fig. 5).

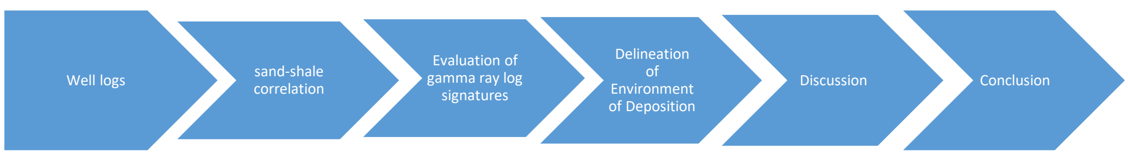

Fig. 4: **Workflow chart**

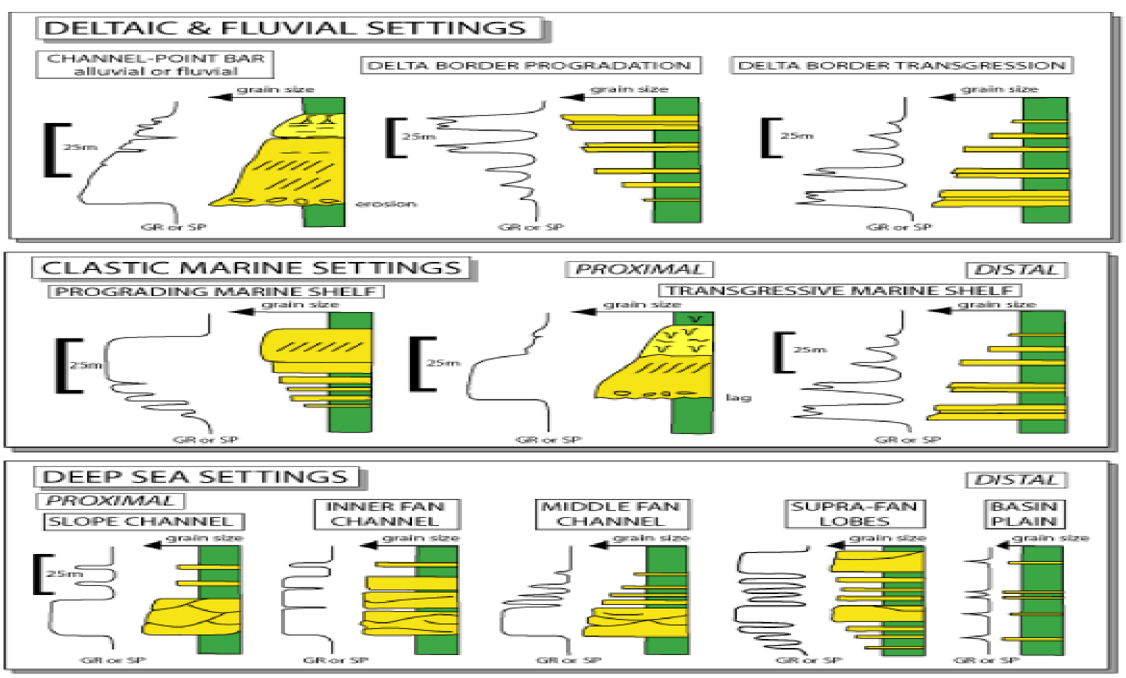

Fig. 5: Gamma-ray log response and depositional environments of deltaic and fluvial,

clastic marine and deep sea settings[8].

Results

Log Motifs and Depositional Energy Trend

The different log motifs were used to determine the vertical trend of sediments of different grain sizes in the gamma log. The overall log shapes within the Akos field reflect changing depositional energy trends from higher to lower realm which was used to deduce depositional environments and other depositional conditions[9]. Analysis of the gamma-ray log trends was classified into the funnel, bell and blocky/serrated log signatures.

3.2 Lithofacies

Four (4) lithofacies were recognized within the stratigraphic column of Akos-field: coarse-grained sandstones, sand-rich heteroliths, facies-3 (mud-rich heteroliths) and facies-4 (mudstone) (Fig. 6)

[8] Kendall, C., 2003. Use of well logs for sequence stratigraphic interpretation of the subsurface. USC Sequence Stratigraphy Web. http://strata.geol.sc.edu/index.html, University of South Carolina.
[9] Ola-Buraimo, A.O, J.E. Ogala, and O.F. Adebayo. 2010. "Well-Log Sequence Stratigraphy and Paleobathymetry of Well-X, Offshore Western Niger Delta, Nigeria". World Applied Sciences Journal. 10(3):330-336.

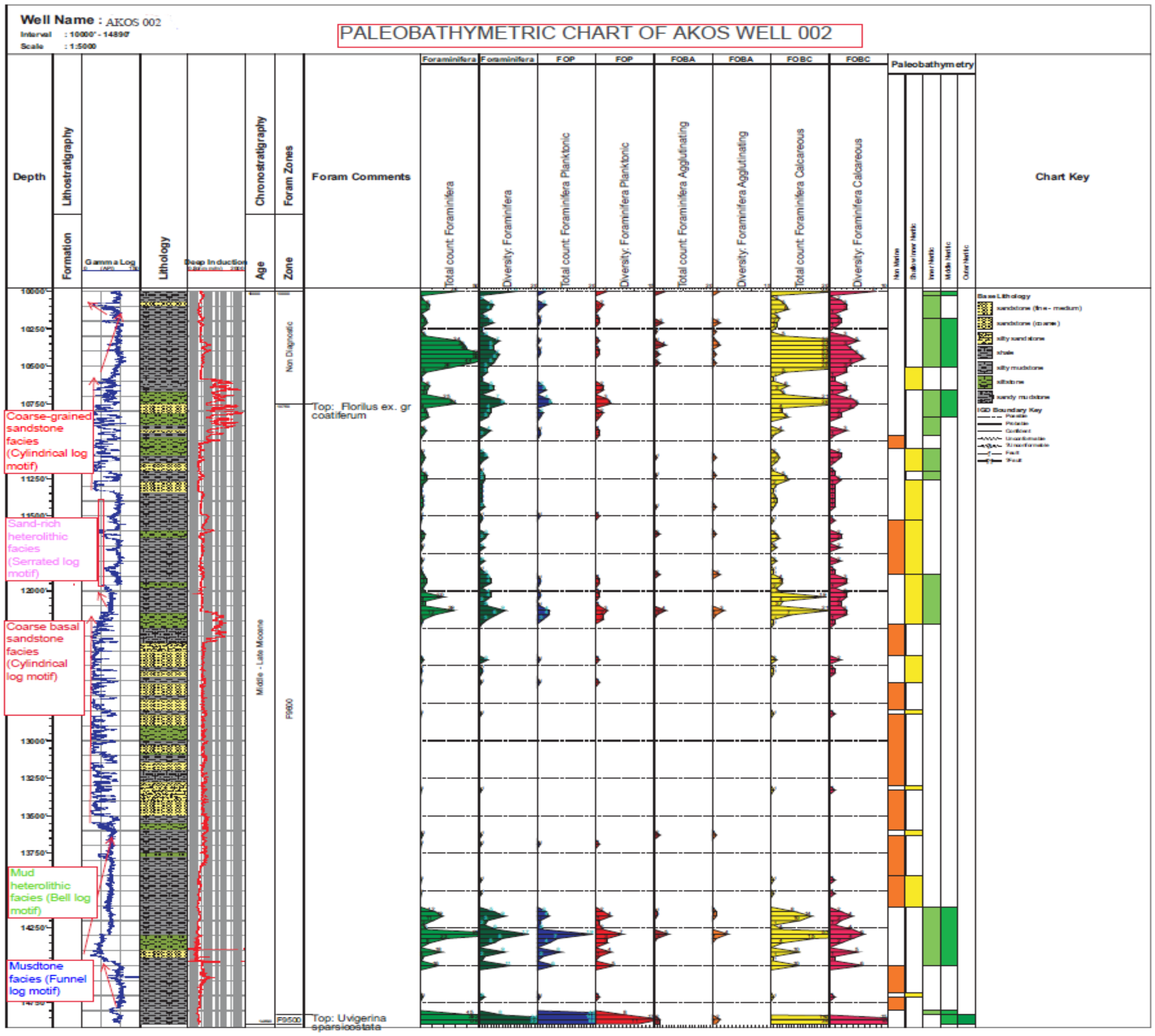

Fig. 6: Paleobathymetry chart of Akos 002 showing the depositional log trends and the different lithofacies

Well Correlation

The lithostratigraphic (sand-sand) correlation was carried out for the subsurface facies of the Agbada Formation penetrated by the wells to determine surfaces along with dip and strike at different depths within the depositional basin in order to depict basin geometry and depositional sequences across the wells.

The log responses within the field are characterized by intercalations of sand and shale. Across the eight (8) wells (Akos 004, 002, 009, 001, 010, 013, 013 and 007) the underlying Agbada Formation constitutes about 60:40 ratio of sand to shale intercalations, while the overlying Benin Formation has a predominantly sand fraction. Ten (10) hydrocarbon-bearing sands, designated A, B, C, D, E, F, G, H, I, and J were identified at the tops and bases as well as their correlation, permitting the establishment of the lateral continuity of the subsurface hydrocarbon reservoir facies penetrated by the wells. Sand A is the shallowest hydrocarbon-bearing reservoir while sand J is the deepest (Fig. 7). All eight reservoirs have representations at both the tops and bases through the wells.

3.3.1 Dip Line Correlation

Three dip sections were delineated based on the dip relationships of the wells in Akos field (Fig.

8) and these include dip line 1 consisting of wells 002, 009 and 008 (Fig. 9); dip line 2-wells 001 and 012 (Fig. 10); and lastly, dip line 3 which comprises of wells 001, 002, 009 and 010 (Fig. 11).

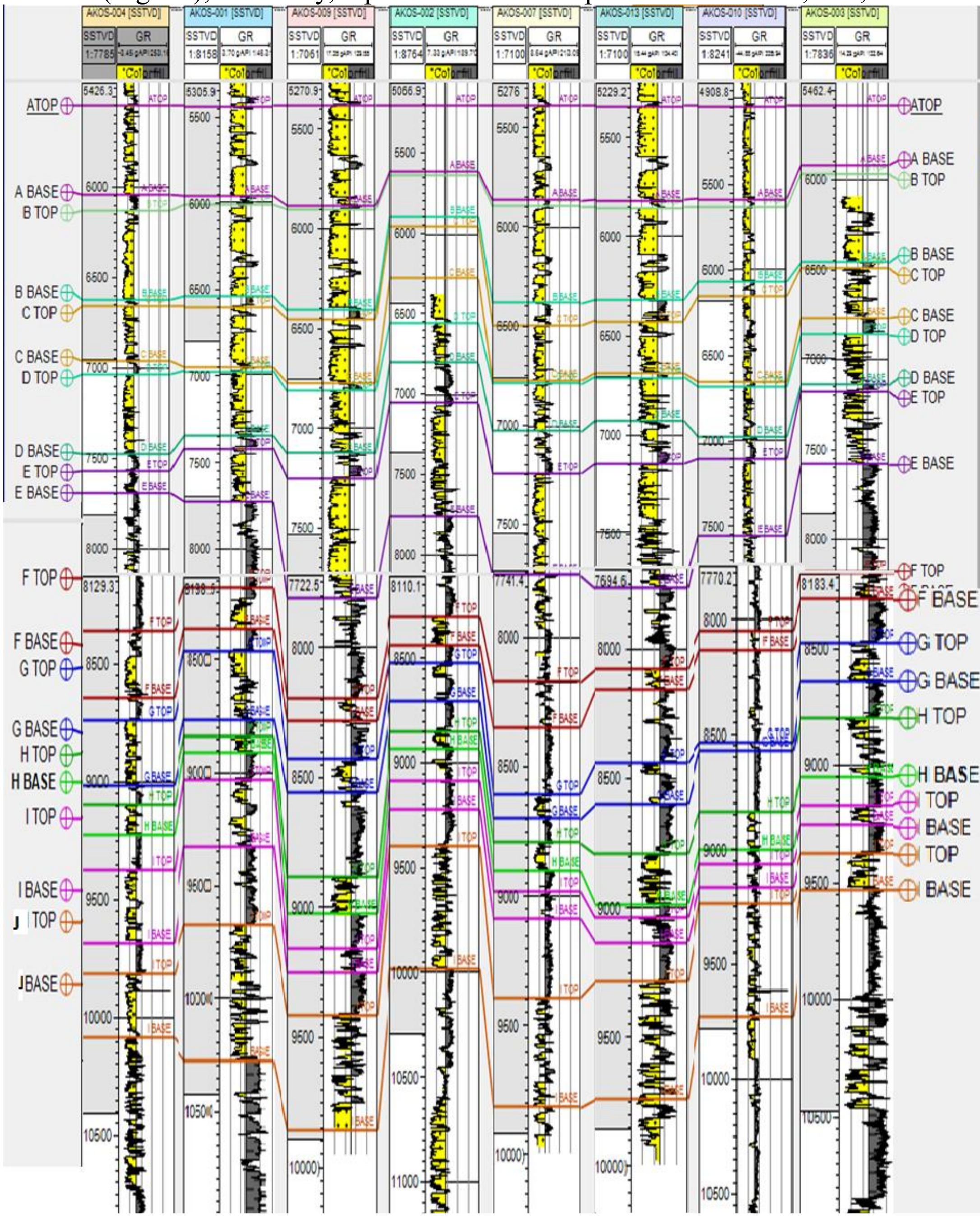

Fig. 7: Continuity of reservoirs across the 8 wells of Akos Field

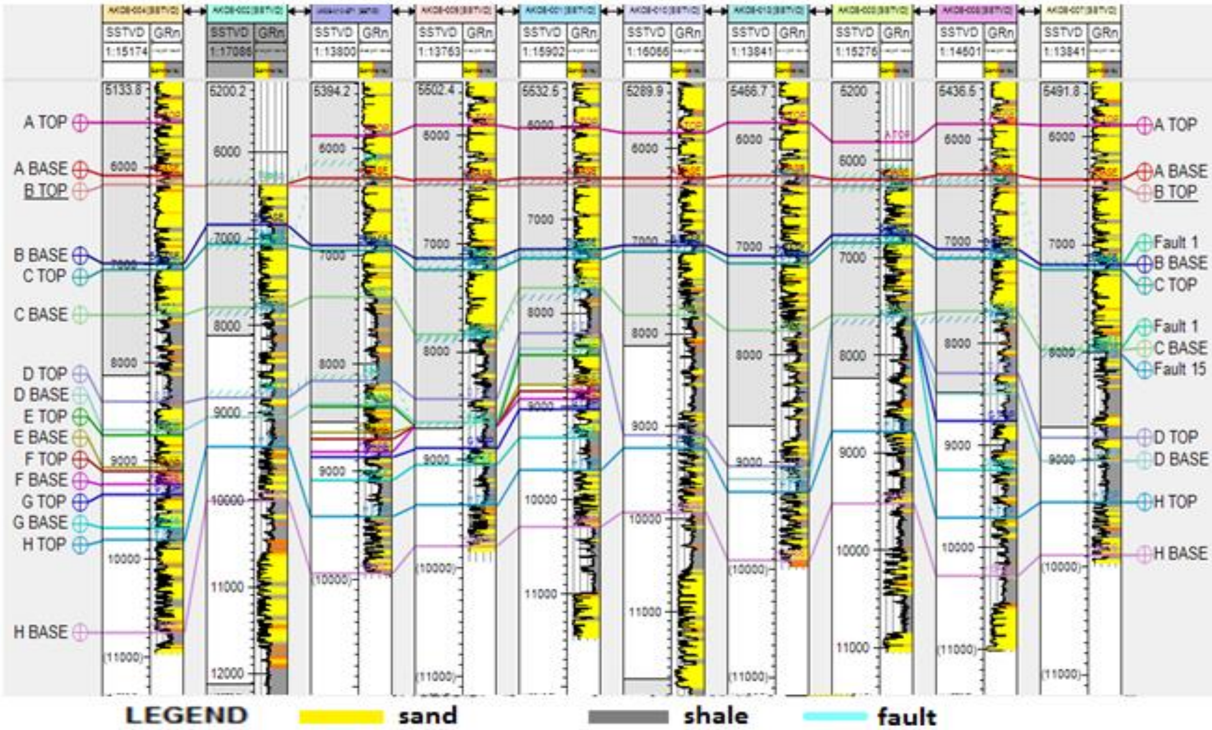

Fig. 8: Well correlation along dip lines with the sand correlation and faults

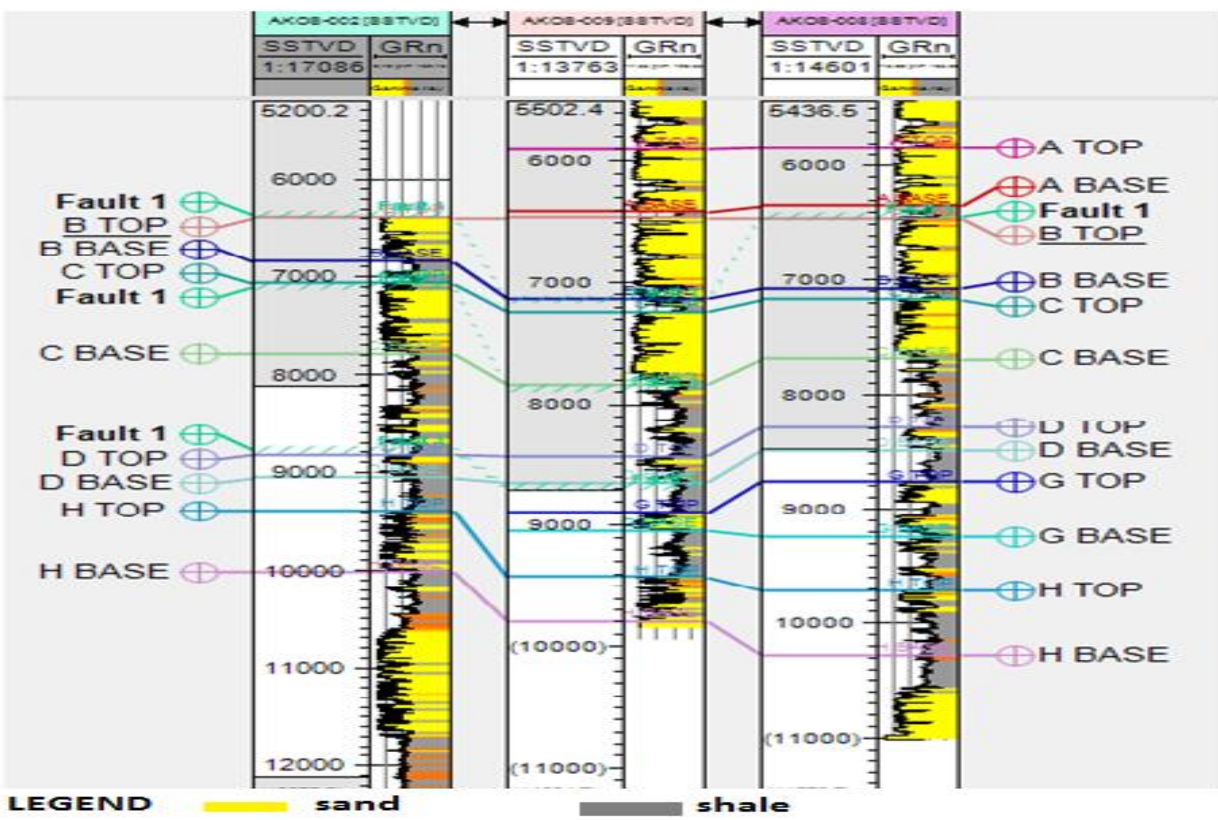

Fig. 9: Down-dip displacement of Akos 002, 008 and 009 along line 1. The apparent displacements indicate the presence of faults.

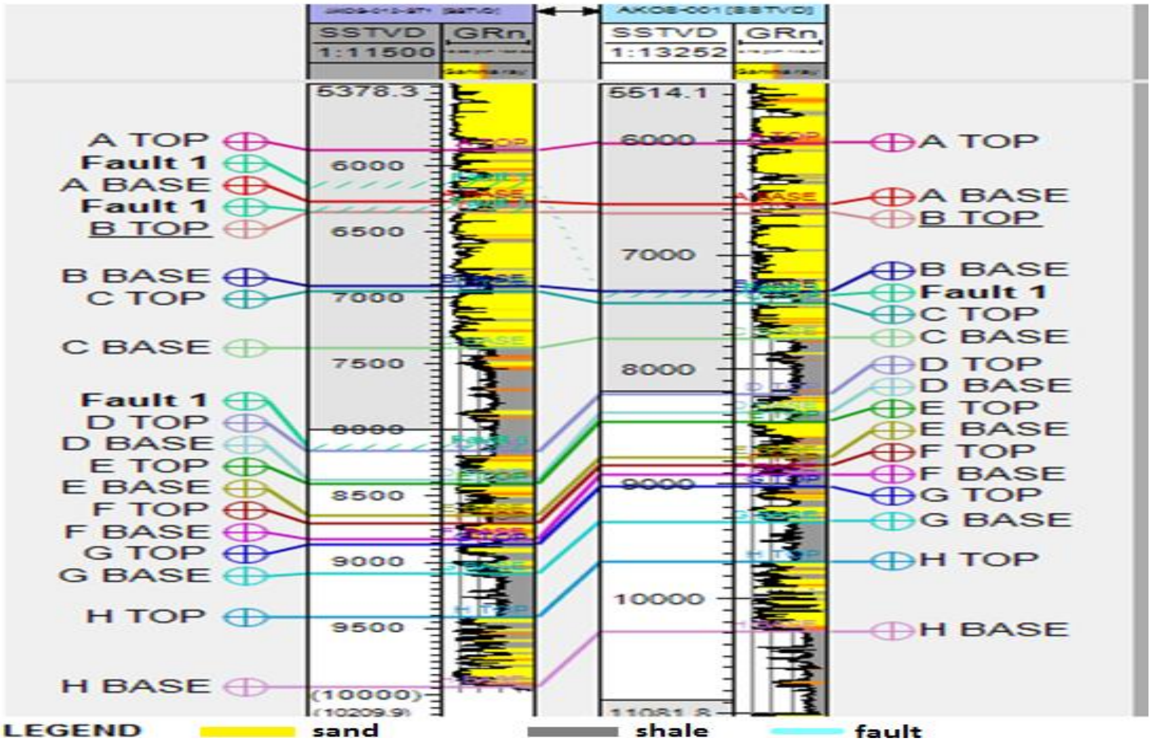

Fig. 10: Down-dip displacement of Akos 001 and 012 along line 2. The apparent displacements indicate the presence of faults.

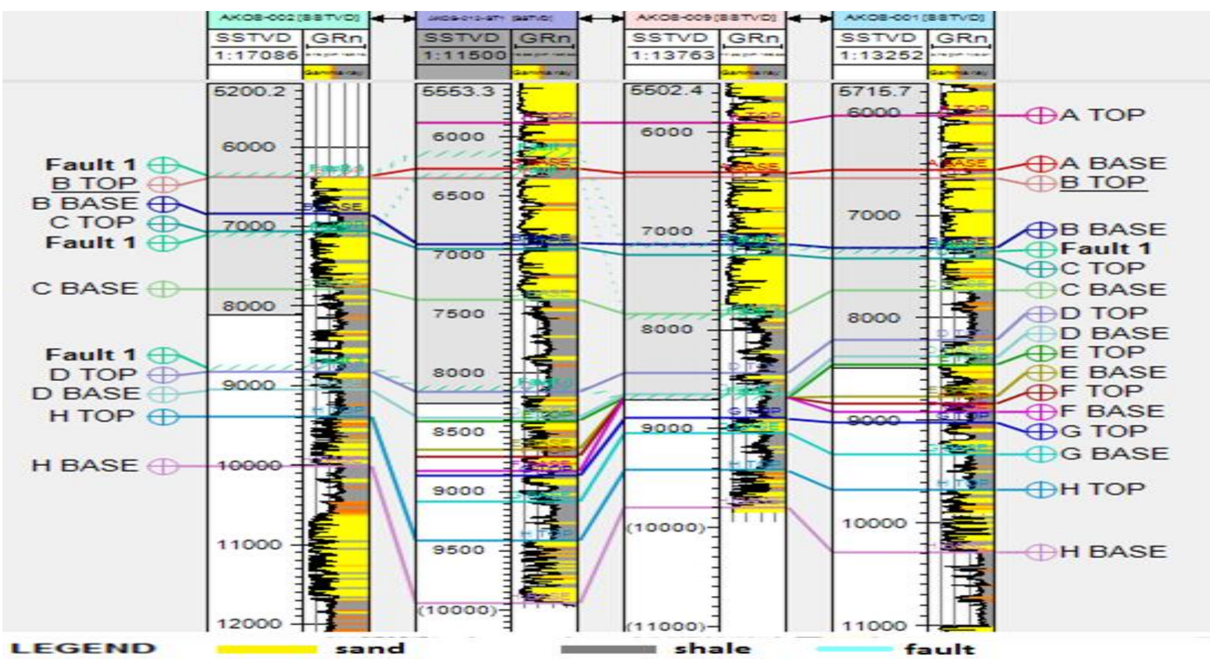

Fig. 11: Down-dip displacement of Akos 001, 002, 009 and 010 along line 3. The apparent displacements indicate the presence of faults.

Discussion

Interpretation of Log Trends

I. Funnel Log Motif

This log pattern was identified within depths 4400m to 4500m an upward coarsening section with decreasing clay content up-section (Fig. 6). The trend reflects a change from the shale-rich lithology at the base to the sand-rich lithology on the top due to deposition in a high energy environment resulting in deltaic progradation. The large thickness of 100m shallowing upward and coarsening succession trend of this log trend is suggestive of a prograding deltaic environment in a shallow marine system[10].

II. Bell Log Motif

This log signature was delineated at a depth range of 4150m to 4400m. Bell-shaped patterns on Gamma Ray logs indicating increasing clay contents up section or fining upward trends or an upward increase in gamma-ray value is a typical feature of fluvial channel/deltaic deposits[11]. This log signature is mostly observed in areas of increase in gamma response reflecting upward fining and a change in lithology from sand to clay. It indicates a decrease in depositional energy causing a shoreline retreat. In the Akos field, this trend was well delineated in the proximal wells in the study area indicating the basinward translation of the facies of the Akata shales in the Niger Delta (Fig. 6).

III. Blocky Log Motif

Blocky log motif was delineated within two sections of the log between depths 3300m to 3400m as well as 3700m to 4130m. They occur as thick uniformly graded coarse-grained sandstones, interpreted to be deposits of a braided channel or tidal channel in the Benin Formation. This pattern indicates remnants of fining and coarsening upward small scale deposit in high energy environment giving rise to a rapid deposit of very coarse sands (channel sands). These sands have sharp bases representing erosional effect of channel-fill succession confined to the fluvial-marine environment[12],[13]. The lack of character in the trend which is seen on most wells in the field is an indication of aggradation of shale and silt. This log response was recognized in all wells of the study area (Fig. 6). The serrated log motif is suggestive of thin shales intercalated within a sandstone body, typically of fluvial, marine and tidal processes.

Lithofacies Interpretation

Four (4) lithofacies were delineated within the stratigraphic column of Akos-field: coarse-grained sandstones, sand-rich heteroliths), facies-3 (mud-rich heteroliths) and facies-4 (mudstone) (Fig. 6)

I. Coarse-grained Sandstone Facies

The coarse-grained sandstone facies consist of fused, isolated sharp-based sand units characterized by a cylindrical gamma-ray log trend (Fig. 6). These sand units are separated by thin bands of shale stone and mudstone, devoid of marine fauna. These facies have an average thickness of 500ft represented in Akos 002. Facies 1 is inferred as a fluvial channel or tidal deposits. These channel deposits are suggestive of deposition in a coastal plain setting landward of the tidal zone. The

[10] Chow, J.J. Li Ming-Ching and Fuh, S., 2005. Geophysical well log study on the paleoenvironment of the hydrocarbon producing zones in the Erchungchi Formation, Hsinyin, SW Taiwan TAO, 16 (3) (2005), pp. 531-543

[11] Selley, R.C. (1998). Elements of Petroleum Geology. Department of Geology, Imperial College, London. pp. 37-145.

[12] Shell. (1982). Well log interpretation: Chapters 11, 12 and 13. Shell Houston

[13] Emery, D. and Myers, K. 1996. Sequence Stratigraphy. Blackwell, London, 297 p.

blocky log pattern is commonly represented in incised valley settings[14].

II. Sand-rich Heterolithic Facies

These facies is characterized by low gamma ray values. It is well represented in all the wells in the Akos Field. The motifs of the logs are mainly serrated and funnel-shaped (Fig. 6) which indicates coarsening upward from mud to shallow marginal marine sandstones. This can be interpreted as a tide-dominated estuarine deposit resulting from the cyclic alternation of sandstones and mudstones[15]. Recurrent alternation of high and low gamma-ray response in serrated and bell/blocky signatures is indicative of frequent fluctuations in the strength of the current during tidal processes and is suggestive of a prograding deltaic environment. Biofacies result displays an increase in foraminifera abundance in a deepwater environment for the mudstone units and low diversity foraminefera forms at the lowest water depths within the sandstone units (Fig. 6).

III. Mud-rich Heterolithic Facies

This facies displays a bell-shaped retrogradational (fining upward) parasequence pattern, composed of shale units with thin siltstone intercalations. Biofacies and well log correlation shows a high frequency and diversity of foraminifera particularly those of the inner neritic depositional environment interpreted as transgressive sands, tidal channel, and marine shale[16].

IV. Mudstone Facies

This facies is represented as a mixture of sandstone and mudstone (Fig. 6). The sandstone has an upward coarsening gamma-ray log motif (Fig. 6). The change in the log trend is indicative of interbedding of fine-grained units within the sandstone. This is suggestive of a prograding delta or lower shoreface sand accumulated within the proximal part of the fluvial marine and inner to middle neritic depositional environments[16].

Reservoir Continuity of the Akos Field

Reservoir-A (Figs. 7) was identified within the upper shoreface. The reservoir is associated with the shoreface depositional system with a concentration of the largest amount of sands. Reservoir B is indicative of the lower shoreface facies with fairly thin seals on its top and base. Reservoir C was mapped within the lower shoreface sands probably formed as a result of the gradual-based forced regressive deposit in the proximal portion of the shallow marine. The reservoir is well represented in all the wells and possesses thin sand bodies with good lateral extent along strike lines. Reservoir D was observed at a depth range of 243m to 274m suggestive of prograding deposits within the transitional environment of the Agbada Formation. Reservoirs E, F, and G top were mapped in all wells of the Akos Field. These reservoirs are suggestive of a fluvial environment. Reservoirs G top and H belong to the upper and lower shoreface sands.

Dip Line Correlation

The displayed correlation panels (Figs. 8, 9, 10 and 11) indicate that the stratigraphic column is dipping in the northeast direction and strikes along the northwest-southeast direction.

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[14] Allen, J. R. L., 1964. The Nigerian Continental Margin; bottom sediments, submarine morphology, and geological evolution, Marine Geology 1, 289-332.

[15] Okengwu, K. O., and Amajor, L. C., 2014. Lithofacies and Depositional Environment Study of the "A1" Reservoir Sand, Well-5, Boga Field, Niger Delta, Nigeria. Inter. Journal of Eng., Sci., and Management. Vol. 4, Issue 4. 2014, pp76-93.

[16] Walker, R. G., and Plint, A. G., 1992. Wave and storm dominated the shallow marine system. In: Walker, R. G., James, N. P. (Eds.), Facies Models: Response to Sea level change Geological Association of Canada, St. John"s pp 219-238.

The correlations showed a normal delta progradation which depicts a coarsening upward profile with continuity of the facies along strike in the east-west direction with minor thickening and thinning in some sequences. The Middle Miocene sequences contain predominantly sandy lithology with intercalations of shale beds which are comparable to other facies of the same age in the Niger Delta. The shaliness of some of the reservoir beds could be indications of the synsedimentary deformation of the Agbada paralic sequence[17,18]. There is also evidence of continuity and connectivity of the reservoir sands that will serve as exploration targets. Results from biofacies also confirm a rapid change in paleobathymetric setting from middle neritic to the shallow inner neritic zone of the marginal marine environment.

4.4 Depositional Environments

Four categories of depositional environments have been recognized in Akos field (Fig. 12). Their identification was based primarily on the pattern of the gamma-ray log signatures and the vertical successions of facies. The environments of deposition include the upper shoreface, lower shoreface, tidal and the transgressive shelf environments.

The shoreface environment is characterized by a coarsening upwards log pattern on the gamma-ray log suggestive of an upward decrease in the shale/clay content from lower shoreface to the upper shoreface and progradation of sediments in consonance with the geology of the Niger Delta. The sandstone deposited in the channel environment is typified by a cylindrical log shape and sharp base on the gamma-ray log. The shelf environment accommodating the transgressive sand revealed serrated log responses suggestive of thin shales intercalated within a sandstone body, typically of fluvial, marine and tidal processes. The depositional environments (Fig. 12) spanned from the shallow Inner Neritic to Middle Neritic and cutting across the upper shoreface, lower shoreface and shelf environment.

[17] Stacher, P., 1995. Present understanding of the Niger Delta hydrocarbon habitat; In M.N. Oti and G.Postma (Eds.), Geology of deltas; A. A. Balkema, Rotterdam; p.257– 267.
[18] Evamy, B.D., Haremboure, J., Kamerling, P., Knaap, W.A., Molloy, F.A.,and Rowlands, P.H., 1978. Hydrocarbon habitat of Tertiary Niger Delta: American Association of Petroleum Geologists Bulletin, Vol. 62, p. 1-39.

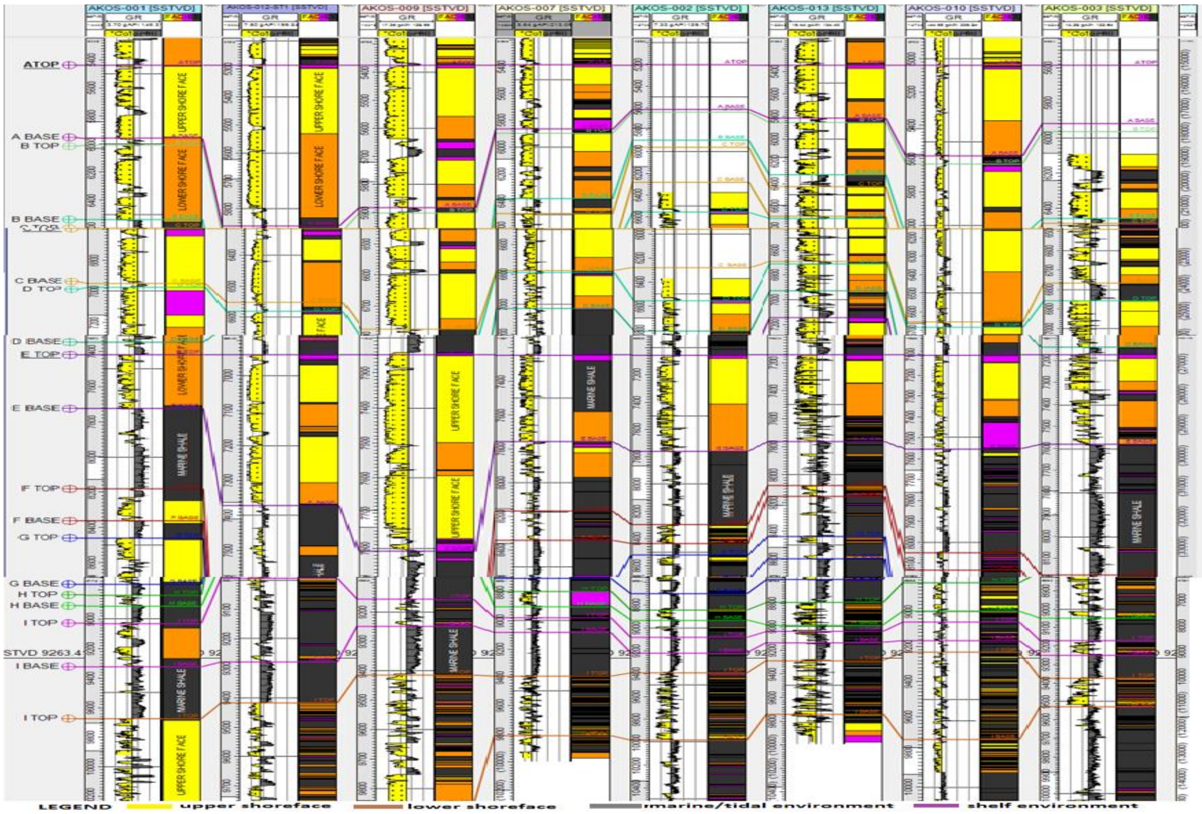

Fig. 12: Delineation of the depositional environments of Akos Field

Conclusion

Ten hydrocarbon sands were delineated from the eight wells in the study using the gamma-ray log. The lithofacies were interpreted based on the changes in log character. Analysis of the gamma-ray log trends was classified into the funnel, bell and blocky/serrated log signatures. The result of the study indicates that the sediments were deposited within the shallow marine to transitional environment settings which consist of the upper shoreface, lower shoreface, fluvial channel, shelf, and tidal environments. Biofacies information from Akos-002 indicated that sediments were generally deposited within shallow Inner-Neritic to the middle Neritic environments at various times, in alignment with the progradational pattern of deposition in the Niger Delta. This study can serve as a basic guide for hydrocarbon sand prospecting and development in the Coastal Swamp Depobelt of the Niger Delta.

Acknowledgments

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